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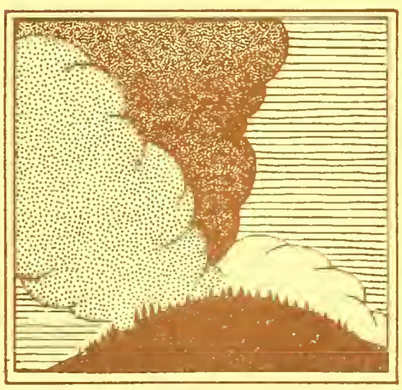
FREQUENCY OF URBAN BUILDING FIRES AS RELATED TO DAILY WEATHER CONDITIONS



DIVISION OF FIRE RESEARCH
FOREST SERVICE
U. S. DEPARTMENT OF AGRICULTURE

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FREQUENCY OF URBAN BUILDING FIRES AS RELATED TO DAILY WEATHER CONDITIONS

by

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ABSTRACT

Daily weather elements of precipitation, wind, mean temperature, relative humidity, and dew-point temperature for selected urban areas (approximately 850,000 population) in the United States are statistically analyzed to determine their correlation with daily number of building fires. The frequency of urban building fires is found to be significantly correlated with relative humidity in summer and dew-point temperature in winter. No significant correlations are found between urban fires and weather elements such as wind, rain, and snow.

Prediction curves relating number of building fires to interior fine fuel moisture content as determined by relative humidity and dew-point temperature for urban areas comparable in size to Baltimore, Maryland, may be obtained from two years of fire and weather records.

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INTRODUCTION

The objective of this study was to find the relationship between current weather elements and building fire starts or ignitions in three urban areas in the United States. Fire frequency is closely associated with fire losses and hence important to the individual, community, and nation.

Fuel moisture content has been found to be one of the most important criterion in ignition and rate of spread of fires (4;5;7, pp. 242-3,254).[1/] It is known to be especially important in the fine wildland fuels as grasses and sedges. Similarly, wildland managers know the moisture content of these fine fuels is affected by the atmospheric humidity and precipitation (9). Early studies by the Japanese have also revealed relative humidity and fuel moisture content to be correlated to urban fire conditions in that country (10).

This study attempts to relate the current weather elements to number of building fire starts and then to provide a useable prediction guide in terms of moisture content of fine fuels within buildings.

PROCEDURE

The cities of Baltimore, Boston, Minneapolis and St. Paul were selected for analysis of fire starts. The climate of these cities permitted study of the influence of both summer and winter weather conditions on fire starts. Fire and weather data for St. Paul and Minneapolis were combined; the two cities were considered as one urban area.

Fire data for several years (Baltimore 1940-1949; Boston 1940, 1941; and Minneapolis-St. Paul 1942-1946) were obtained from the official logs through the cooperation of the fire chiefs. These data were best stratified to include only fires originating within a structure, thus eliminating automobile, dump, power pole, tree, and explosion fires.

Weather data were tabulated from monthly climatological summaries (WB Form 1030) of the local U. S. Weather Bureau office in each of the four cities. Weather elements which were considered as possibly influencing the start of urban fires were maximum wind speed, mean temperature, precipitation, maximum and minimum temperature,

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1/ Underlined numbers in parentheses refer to Literature Cited, page 20.

relative humidity, and dew-point temperature. Snow, sleet, and hail were included in the rain data as water equivalents. Relative humidity and dew-point temperature data taken from the weather records were those closest to local noon. For days when the mean temperature was not given in the record it was determined by the standard procedure of averaging the recorded daily maximum and minimum temperature.

Most urban fires inside buildings are started by ignition of fine or kindling materials such as paper or textiles, i.e., substances having little weight in proportion to bulk.[2/] These fine fuels in turn ignite the heavier secondary fuels within the structure. It is assumed that moisture content of interior fuels is near the equilibrium moisture value and is closely related to the exterior relative humidity when mean temperature is above 65°F and to the exterior dew-point temperature when mean temperature is below 65°F. It is assumed that artificial heat is used in buildings to maintain human comfort whenever the daily mean temperature is below 65°F. Determination of interior fuel moistures from these two variables is discussed more fully in the appendix.

An average equilibrium moisture content curve was established for the most common fine fuels which are newsprint, writing paper, Kraft wrapping paper, wool skein, and cotton cloth (Table 3, Appendix). Moisture content of fine interior fuels is determined by Table 4 (Appendix), using relative humidity when outside mean air temperature is 65°F or above, and dew-point temperature when mean air temperature is 65°F or below.

Four analyses were made to find the relationships between moisture content of interior fine fuels and urban building fire starts as affected by weather variables. The objectives of these analyses were:

1. To study the influence of precipitation, relative humidity, maximum wind, daily mean temperature, and dew-point temperature on the daily number of building fires. Sixty-two consecutive days of high and low fire frequency for both winter and summer seasonal conditions were studied for the urban areas of Baltimore and Minneapolis-St. Paul.

2. To determine the possible cumulative effects of previous fuel moisture condition on fire starts. Three-day and five-day cumulated averages of fuel moisture for the identical time period described in the above analysis.

2/ Specific origins of fires are frequently not listed by fire departments because they are destroyed in the ensuing fire and hence are unknown. Therefore, a small number of fires may have originated in other than fine fuels.

3. To study the relationship of daily fire frequencies to the computed daily fine fuel equilibrium moisture contents for all available fire data for Baltimore, Boston, and Minneapolis-St. Paul.

4. To find the quantity of data needed to establish the significant relationship between fuel moisture and number of daily fire starts.

RESULTS AND DISCUSSION

The results of the correlation analysis of each weather variable compared to the daily number of building fires is shown in Table 1 for Baltimore and Minneapolis-St. Paul. Correlation coefficients for each of the weather variables considered are listed for the 62 consecutive day test periods.

Precipitation and wind are found by the correlation analysis not to be significantly related to fire starts. This is logical since structures are built to keep out the rain and wind. Logbook data, for the cities analyzed, showed many fires occurring in rain storms and blizzards. Therefore precipitation may be disregarded as one of the critical variables.

Analysis of the daily mean temperature showed positive and negative correlations with number of fires during the periods of high fire frequencies. During cold winter periods, the interiors of buildings are found to become dry (8). This dryness is partially explained by the fact that inside surfaces of single-pane windows are at a lower temperature than the air within a room. Window surfaces then act as a collector of excess moisture for the interior atmosphere (12).

The importance of this phenomenon on interior fuel moistures is shown in Figure 1. Using known heat transfer coefficients of glass, surface temperatures of inside windows may be calculated (2,p.203). Interior relative humidities corresponding to a room temperature of 65°F then may be estimated.

Even though the daily mean temperature was significant in winter, it will be noticed that the dew-point temperature of the outside atmosphere was more highly significant during the colder periods. This is because the dew-point temperature combines the effects of the external air temperature and absolute humidity.

Relative humidity, as revealed in the correlation analysis, exhibits highly significant relationships with fire frequency. The significant humidity correlations exist more generally during the summer except in the summer period of low fire frequency at Minneapolis-St. Paul. The frequencies are too low in the latter case to provide an adequate basis for this type of analysis.

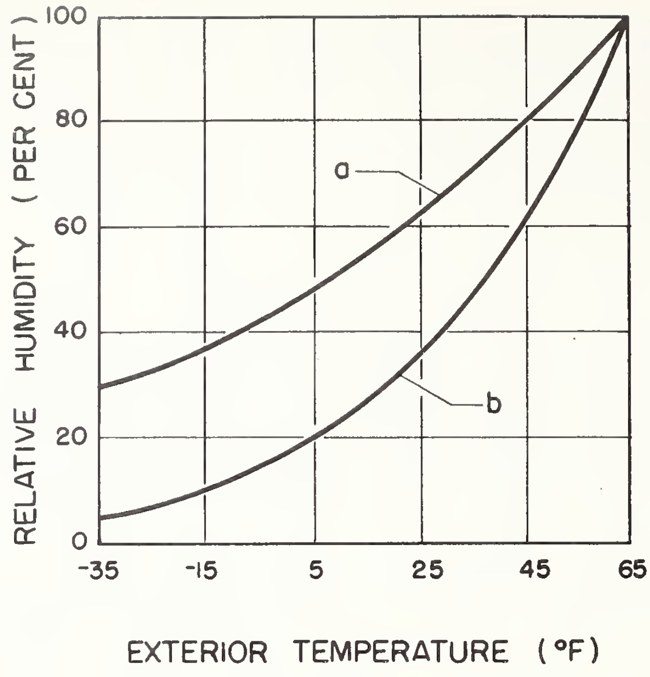

Figure 1.--Maximum relative humidity within buildings prior to condensation of excess moisture on windows. For building air temperature at 65^{o}F, (a) double pane window glass, (b) single pane window glass.

Although the humidity correlation is acceptably significant in winter in Minneapolis-St. Paul, it can be seen from Table 1 that the dew-point temperature is even more so. Extensive summer dry periods with low humidities act similar to the winter cold spells in lowering the fuel moisture.

Relative humidity influences the moisture exchange process of both fine and heavy hygroscopic material. In heavy material this exchange of moisture is less rapid as shown in the U. S. Forest Products Laboratory analysis (8) of moisture content of wood structures in various cities throughout the country. Heavier material is shown to actually reflect seasonal, rather than daily weather changes. Low moisture contents were found to occur in the summer in the Southwest and in the winter throughout the rest of the United States.

Comparisons of the daily fuel moisture contents and the cumulative averages of 3- and 5-day consecutive periods to the corresponding frequency of building fires are shown in Table 2. The time periods covered are identical to the weather element analysis. Number of fires was found more closely related to daily than 3- or 5-day moisture content of fine fuels. This significance is logically explained on the basis that the fine fuels respond quickly to changes in air moisture.

Table 1.--Correlation analysis of weather elements and daily number of urban building fires

Urban fire condition[1]	Average number fires per day	Correlation coefficients[2] Wind	Air temperature	Relative humidity	Precipitation	Dew point temperature
BALTIMORE, MD.						
Winter-high frequency Dec. 1947-Jan. 1948	24	-.132	-.514	-.168	(3/)	-.447
Winter-low frequency Dec. 1940-Jan. 1941	14	+.238	-.147	-.551	(3/)	-.526
Summer-high frequency July-Aug. 1949	12	+.206	+.395	-.624	+.033	+.066
Summer-low frequency July-Aug. 1940	8	+.267	+.237	-.349	(3/)	-.021
MINNEAPOLIS-ST. PAUL, MINN.						
Winter-high frequency Dec. 1943-Jan. 1944	10	+.124	-.591	-.324	+.078	-.631
Winter-low frequency Dec. 1945-Jan. 1946	9	-.160	-.689	-.454	-.232	-.705
Summer-high frequency July-Aug. 1946	8	+.046	-.210	-.531	-.0005	-.444
Summer-low frequency July-Aug. 1942	5	+.207	-.005	-.087	-.068	+.004

1/ Sixty-two consecutive days analyzed in each frequency period of high and low numbers of fires.

2/ Correlation coefficient significance levels with 60 degrees of freedom (i.e., 62-2) are 0.325 at 1 percent level and 0.250 at 5 percent level (11,pp.148-155).

3/ Data missing.

Table 2.--Correlation analysis of cumulative effects of 3- and 5-day to daily fine-fuel equilibrium moisture content and corresponding frequency of building fires

Urban fire condition	Average number fires per day	Correlation coefficients 1/		
		Daily	3-day	5-day
BALTIMORE, MD.				
Winter-high frequency Dec. 1947-Jan. 1948	24	-.374	-.348	-.331
Winter-low frequency Dec. 1940-Jan. 1941	14	-.569	-.557	-.455
Summer-high frequency July-Aug. 1940	12	-.364	-.347	-.344
Summer-low frequency July-Aug. 1949	8	-.563	-.384	-.277
MINNEAPOLIS-ST. PAUL, MINN.				
Winter-high frequency Dec. 1943-Jan. 1944	10	-.526	-.380	-.250
Winter-low frequency Dec. 1945-Jan. 1946	9	-.641	-.547	-.427
Summer-high frequency July-Aug. 1946	8	-.517	-.361	-.237
Summer-low frequency July-Aug. 1942	5	-.047	-.143	-.219

1/ Correlation coefficient significance level with 60 degrees of freedom is 0.325 at 1 percent level (11, pp.148-155).

The analysis for Baltimore, Boston, and Minneapolis-St. Paul included weather and fire data for 10, 2, and 5 years, respectively. The average daily number of building fires for the computed fuel moisture content class (i.e., from 1 to 20 percent) is presented in Figure 2. Also shown are the maximum number of fires in each class. Results for Boston and Minneapolis-St. Paul include all weather and fire data available for this study. The results for Baltimore represent every other week for the 10-year period. The double curves

reflect the variation that was found in this study. Further analysis of more stratified data might offer additional information that would present a better distribution pattern.

Variations in fire starts between the cities pose some questions not answered in this paper. The difference between Minneapolis-St. Paul and Baltimore are logical because of Baltimore's greater population. Variations between Baltimore and Boston, cities almost equal in population, are apparently not due to the population densities. There were insufficient data to determine the reasons for the differences.

An analysis of all Baltimore data shows an apparent upward trend in number of fires from 1940 to 1949. Comparison of deviations from the mean of fire starts in each moisture content class exhibit no greater variation between consecutive years or between early and late years in the period studied (Figure 2). The means show an increasing trend that appears to correspond with the growth of Baltimore. To establish a significant relationship between fuel moisture and fire starts for an area such as Baltimore, it appears from Figure 3 that one need only use data for the most recent 2-year period.

CONCLUSIONS

1. The frequency of fire starts in urban buildings is related inversely to the moisture content of interior fine fuels as determined by relative humidity in summer and dew-point temperature in winter.

2. No significant correlations were found between urban fire starts and weather elements such as wind, rain, and snow for all seasons or mean temperature in summer.

3. For cities comparable in size to Baltimore, Maryland, two years' data of fire starts and corresponding weather conditions are sufficient to provide a significant relationship between urban fire starts and equilibrium moisture content of fine fuels.

4. Cumulative effects of previous moisture conditions on current fire starts are insignificant because the response of fine fuels to moisture changes in the air is rapid.

5. Reasons for variations in fire starts between cities of the same population class cannot be assessed with unstratified weather and fire data on hand.

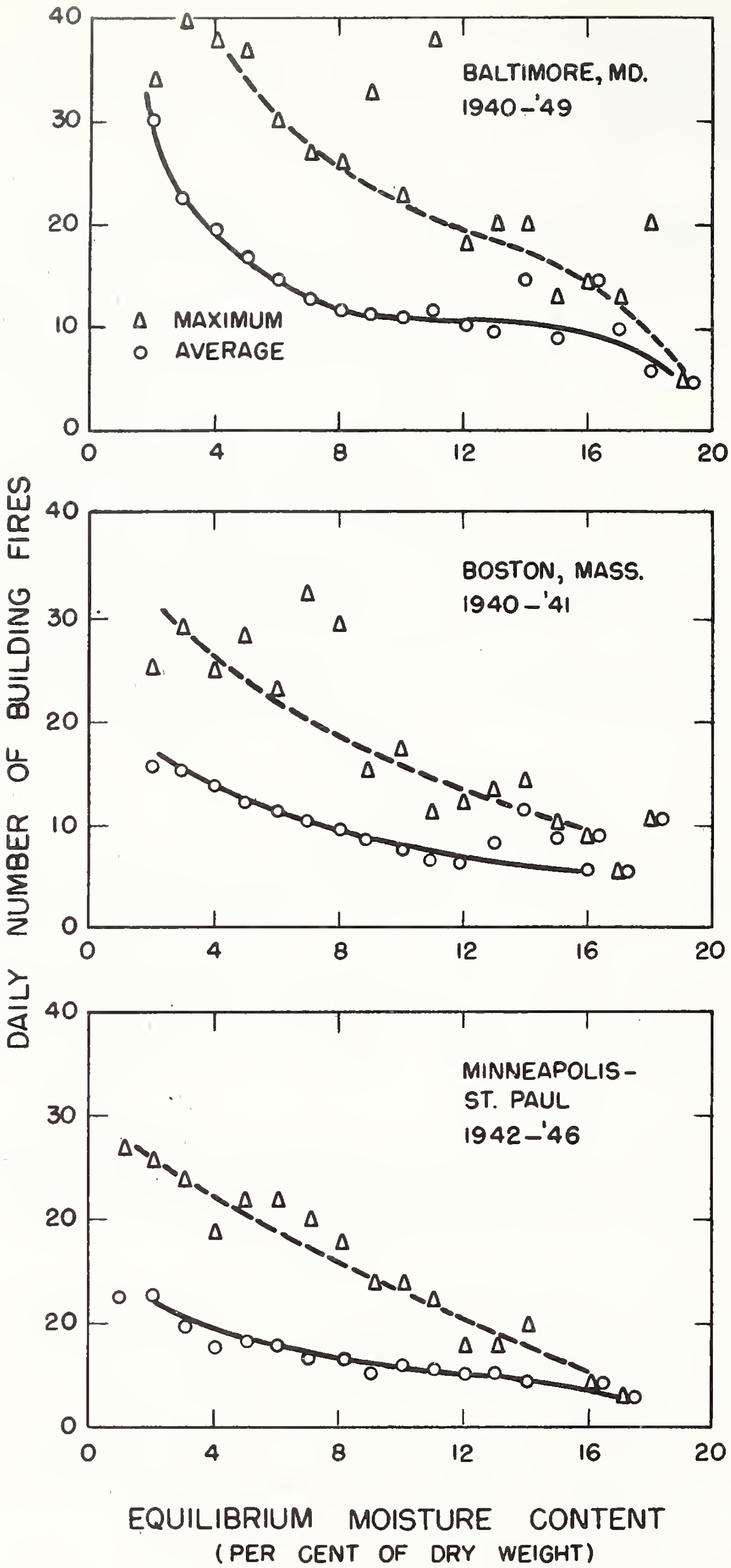

Figure 2.--Relationship of daily number of building fires and equilibrium moisture content of interior fine fuels in three United States cities. Baltimore represents data from every other week in the period, whereas all data were utilized in analysis of Boston and Minneapolis-St. Paul.

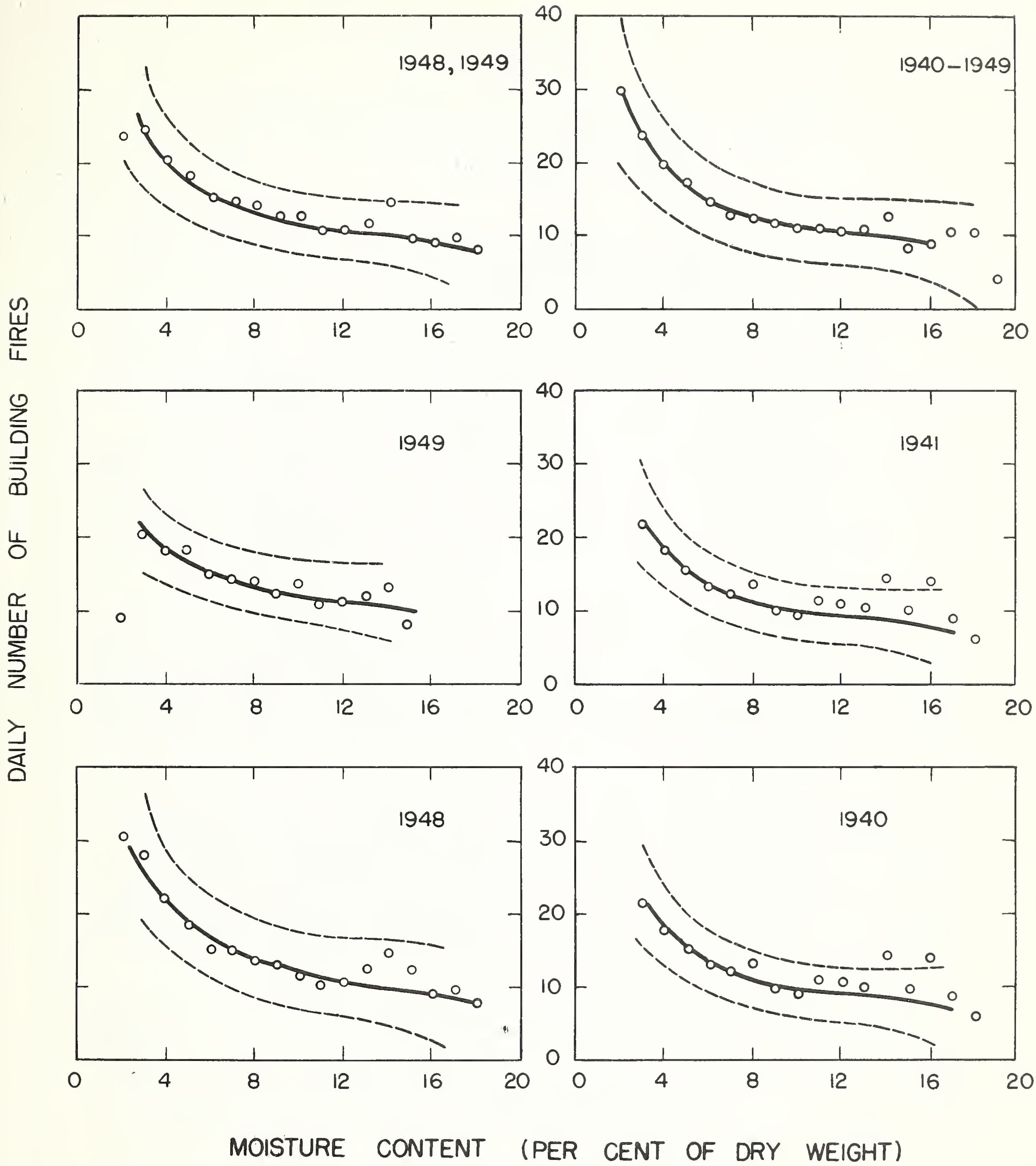

Figure 3.--Relationship of means and standard deviations of means of daily number of building fires and interior fine fuel moisture content in Baltimore, Maryland for various periods of time. Data represents daily computations. Solid lines are means, dashed lines are limits of one standard deviation (11, pp. 148-155).

APPENDIX

DETERMINATION OF EQUILIBRIUM MOISTURE CONTENT OF FINE MATERIALS WITHIN ENCLOSED STRUCTURES AS AFFECTED BY EXTERIOR WEATHER ELEMENTS

For weather elements to affect the moisture content of fine fuels within enclosed structures, they must be able to diffuse through the roof and walls. The only weather element capable of penetrating walls of a structure by diffusion is water vapor.

The average equilibrium moisture content of fine fuels is a nonlinear increasing function of relative humidity and temperature (Table 3 and Figure 4). In addition to closing windows and doors occupied structures were assumed to employ artificial internal heat whenever exterior temperatures averaged below 65°F so as to maintain human comfort. If the interior temperatures average 65°F in urban homes, retail stores, warehouses, and factories, it is then known that the pressure of saturated water vapor is a nonlinear increasing function of temperature. With fixed indoor temperature, it is clear that the pressure of saturated water vapor indoors is therefore constant.

The relative humidity is the ratio of the pressure of the water vapor actually present in the atmosphere to the pressure which would be exerted by water vapor if the atmosphere were saturated in the existing temperature. Therefore, at a fixed temperature the relative humidity inside varies directly as the vapor pressure inside, or the equilibrium moisture content of fine fuels inside is a nonlinear increasing function of the vapor pressure inside.

Although internal and external temperatures are not equal, the vapor pressure inside attempts to equal the vapor pressure outside because of leaks at window sashes and doors and diffusion through the walls themselves. Exact equal vapor pressures are prevented because of the diffusion resistances (12). However, the equilibrium moisture content of interior fine fuels is an approximate nonlinear increasing function of exterior vapor pressure.

At a constant total pressure, the dew-point temperature is a nonlinear increasing function of outside vapor pressure. Hence, the equilibrium moisture content of interior fine fuels is a nonlinear increasing function of the exterior dew-point under the above-assumed conditions. More rapid outward flow of moisture results with lowering external dew-point temperature because the vapor pressure gradient becomes greater.

Water vapor in the outside atmosphere can move freely in and out of structures when windows are opened in summer or when the average outside mean air temperature is 65°F or greater. Unheated buildings in wintertime also have interior moisture contents affected by exterior humidities since interior and exterior partial vapor pressures are in equilibrium because of similarities in air temperature.

Table 3.--Equilibrium moisture content percent of some fine materials at surround air temperature of 75°F[1/]

Material	Relative humidity (percent)								
	10	20	30	40	50	60	70	80	90
	Equilibrium moisture content (percent)								
Cotton cloth	2.6	3.7	4.4	5.2	5.9	6.8	8.1	10.0	14.3
Wool skein	4.7	7.0	8.9	10.8	12.8	14.9	17.2	19.9	23.4
Newsprint	2.1	3.2	4.0	4.7	5.3	6.1	7.2	8.7	10.6
Writing paper	3.0	4.2	5.2	6.2	7.2	8.3	9.9	11.9	14.2
Kraft wrapping paper	3.2	4.6	5.7	6.6	7.6	8.9	10.5	12.6	14.9
Average[2/]	3.1	4.5	5.6	6.7	7.8	9.0	10.6	12.6	15.5

1/ See reference (1).
2/ Average almost identical as Kraft wrapping paper.

The majority of fine materials are hygroscopic by nature, in that they can readily take on, retain, and give up moisture to the surrounding atmosphere (3). This moisture is held directly in the fibers of most materials. Synthesized plastic fabrics differ in that small quantities of water are held between two or more fiber surfaces where the fibers cross one another.

Various papers and textiles were selected to represent the most common types of fine materials found inside buildings. These materials are cotton cloth, wool, newsprint, writing paper, and wrapping paper. Their equilibrium moisture contents (1) for various relative humidities are shown in Table 3. For this analysis, the average values in Table 3 were used to represent the relationship of moisture content of fine materials to relative humidity (Figure 4). By using Marvin's psychrometric tables (6) the relationship of dew-point temperatures to relative humidities at 65°F was obtained (Figure 5).

For each equilibrium moisture content from 1 to 20 percent, the corresponding relative humidity reading was recorded in Table 4. To represent conditions in heated buildings, that is, when outside air temperatures are below 65°F, the appropriate dew-point temperatures for the corresponding humidities in Figure 5 are also recorded in Table 4.

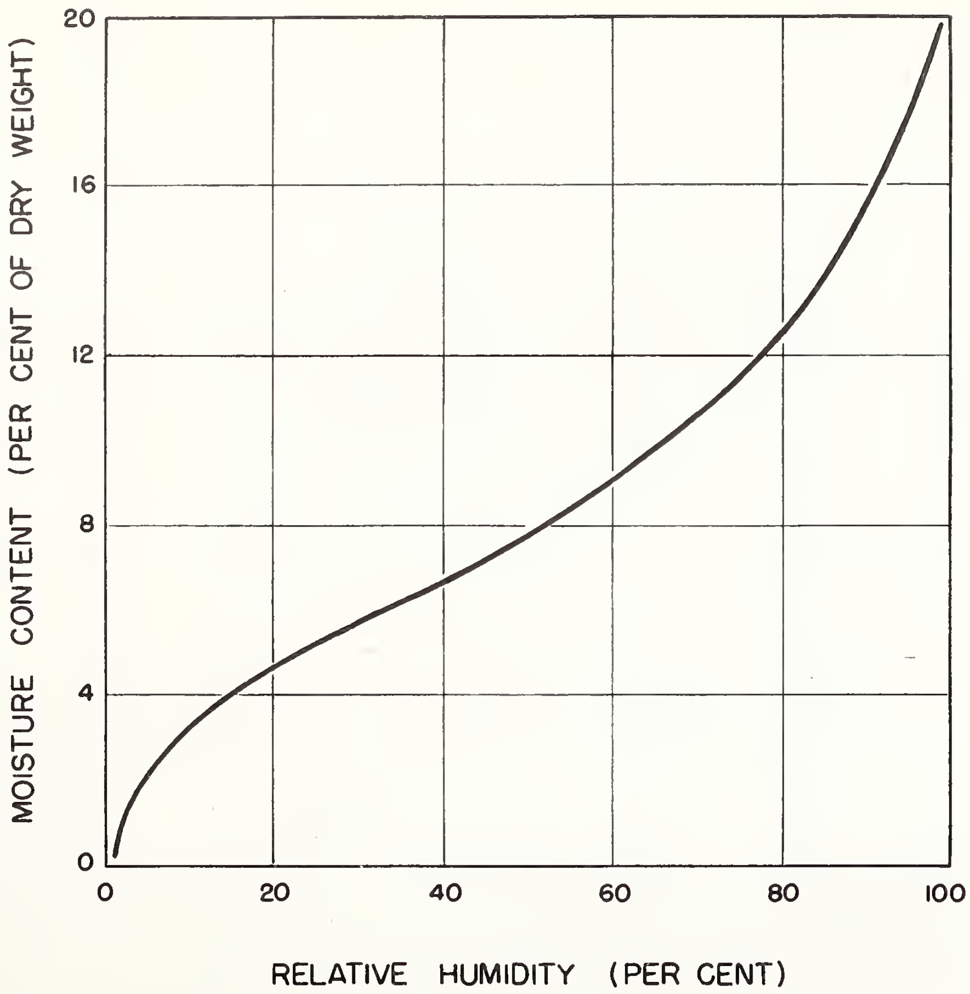

Figure 4.--Average equilibrium moisture content for fine fuels as a function of relative humidity for a surround temperature of 75°F.

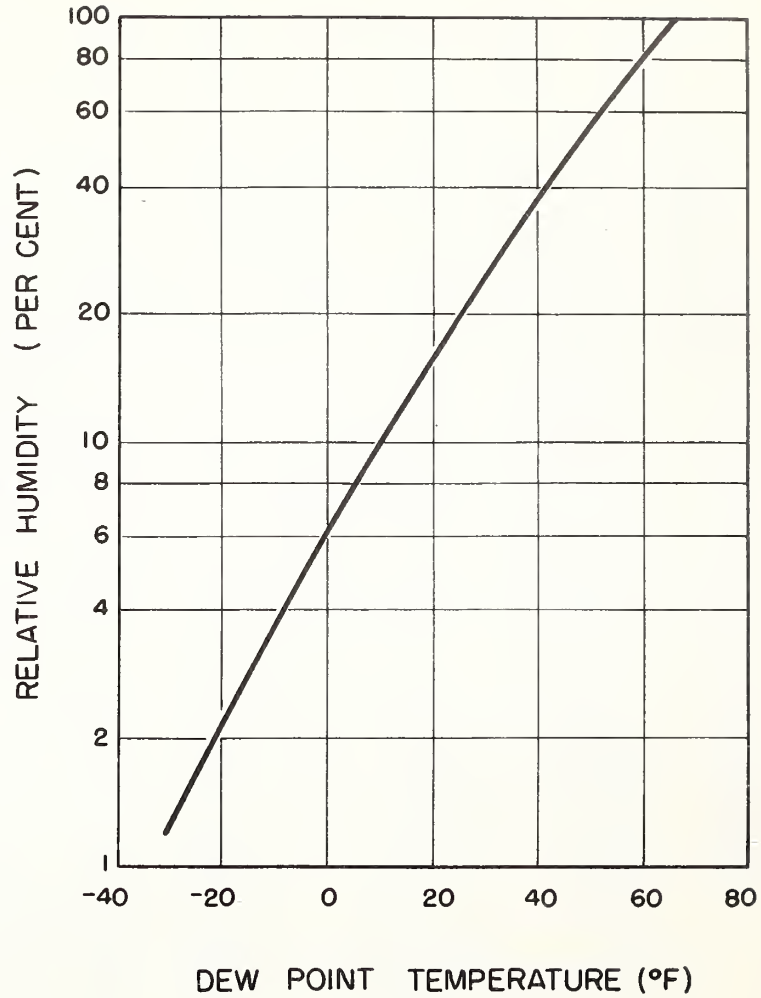

Figure 5.--Relationship of dew-point temperatures to relative humidities at 65°F.

Table 4.--Estimate of equilibrium moisture content of interior fine fuels[1/]

Relative humidity	Dew-point temperature	Fine fuel moisture content
percent	°F	percent
2 or less	-18 or less	1
3 - 7	-17 to +2	2
8 - 13	3 - 15	3
14 - 21	16 - 25	4
22 - 30	26 - 34	5
31 - 39	35 - 40	6
40 - 48	41 - 46	7
49 - 56	47 - 50	8
57 - 64	51 - 53	9
65 - 71	54 - 55	10
72 - 76	56 - 57	11
77 - 81	58 - 59	12
82 - 84	60 - 61	13
85 - 88	62	14
89 - 91	63	15
92 - 93	64	16
94 - 95	65	17
96 - 97		18
98 - 99		19
100		20

1/ Use exterior dew-point temperatures when daily mean air temperature is 64°F or below, and relative humidity when daily mean air temperatures are 65°F or above.

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Director of Intelligence, Headquarters, USAF, Washington 25, D.C. ATTN: AFOIN-1B2	2
The Surgeon General, Headquarters, USAF, Washington 25, D.C. ATTN: Bio Defense Br., Prev Med Division	1
Commander-in-Chief, Strategic Air Command, Offutt AFB, Nebraska ATTN: Chief, Operations Analysis	1
Commander, Tactical Air Command, Langley AFB, Va. ATTN: Doc Sec Branch	1

ADDRESSEE AIR FORCE (Cont'd)	NO OF CYS
Commander, Air Defense Command, Ent AFB, Colorado	1
Commander, Air Materiel Command, Wright-Patterson AFB, Ohio	2
Commander, Air Training Command, Scott AFB, Ill. ATTN: DCS/O GTP	1
Commander, Air Research and Development Command, P.O. Box 1395, Baltimore 3, Md. ATTN: RDDN	3
Commander, Air Proving Ground Command, Eglin AFB, Fla. ATTN: AG/TRB	1
Director, Air University Library, Maxwell AFB, Ala.	2
Commander, Flying Training Air Force, Waco, Texas ATTN: Director of Observer Training	2
Commander, Crew Training Air Force, Randolph AFB, Randolph Field, Tex. ATTN: 2GTS, DCS/O	1
Commander, Technical Training Air Force, Gulfport, Miss. ATTN: TA/D	1
Commander, USAF School of Aviation Medicine, Randolph AFB, R ndolph Field, Texas	2
Commander, Wright Air D velopment Center, Wright-Patterson AFB, Ohio ATTN: WCOSI	1
Commander, AF Cambridge Research Center, L. G. Hanscom Field, Bedford, Mass. ATTN: CRQST-2	1
Commander, AF Special Weapons Center, Kirtland AFB, N. M. ATTN: Library	3
Commander, USAF Institute of Technology, Wright-Patterson AFB, Ohio ATTN: Resident College	1
Commander, Lowry AFB, Denver, Colo. ATTN: Dept of Armament Training	1
OTHER DOD ACTIVITIES	
Director, Weapons Systems Evaluation Group, OSD, Washington 25, D. C.	1
U.S. Documents Officer, Office of the United States National Military Representative - SHAPE, APO 55, New York, N. Y.	1
Assistant Secretary of Defense, (Research and Development), Washington 25, D.C. ATTN: Tech Library	1
Commandant, Armed Forces Staff College, Norfolk 11, Va. ATTN: Secretary	1

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ADDRESSEE	NO OF CYS
OTHER DOD ACTIVITIES (Cont/d)	
Commander, Field Command, AFSWP, PO Box 5100, Albuquerque, N.M.	6
Chief, Armed Forces Special Weapons Project, Washington 25, D.C.	15
PANEL ON THERMAL RADIATION	
Massachusetts Institute of Technology, Director, Division of Defense Laboratories, Lincoln Laboratory, Cambridge 19, Mass. (For Prof Hoyt C. Hottel)	1
Director, U.S. Naval Research Laboratory, Washington 25, D.C. ATTN: Dr. E. O. Hulburt	1
University of Rochester, Atomic Energy Project, P.O. Box 287, Station 3, Rochester 20, New York ATTN: Tech Report Control Unit (For Dr. Herman E. Pearse)	1
Commander, U.S. Naval Air Development Center, Johnsville, Pa. ATTN: Dr. J.D. Hardy, Aviation Medical Acceleration Lab	1
OTHERS	
Sandia Corporation, Sandia Base, Albuquerque, New Mexico ATTN: Classified Document Div (For Dr. E. F. Cox)	1
Los Alamos Scientific Laboratory, P.O. Box 1663, Los Alamos, N.M. ATTN: Report Librarian (For Dr. Alvin C. Graves, J-Division)	1
Los Alamos Scientific Laboratory, P.O. Box 1663, Los Alamos, N.M. ATTN: Report Librarian	1
Medical College of Virginia, Box 222, Richmond, Va. ATTN: Maj Gen W. F. Tomkins (For Dr. William T. Ham)	1
Director, California Forest and Range Experimental Station, U.S. Forest Service, P.O. Box 245, Berkeley, C lif. ATTN: W.L. Fons, Div. of Forest Fire Research	1
Massachusetts Institute of Technology, Director, Division of Defense Labs, Lincoln Lab, Cambridge 19, Mass. (For Prof. G.C. Williams)	1
Mr. H.D. Bruce, Forest Products Lab, North Walnut Street, Madison 5, Wisconsin	1
Chief, Fire Research Division, Forest Service, U.S. Department of Agriculture, Washington 25, D.C. ATTN: Mr. A. A. Brown	1
Technical Operations, Inc., 6 Schouler Court, Arlington 74, Mass. ATTN: Security Officer (For Dr. Frederick C. Henriques)	1